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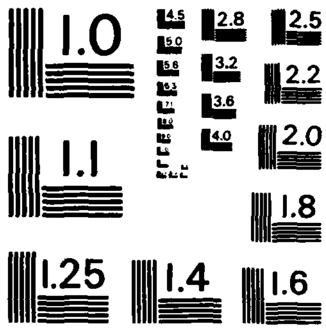

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Phonemic restoration is a powerful auditory illusion that arises when a phoneme is removed from a word and replaced with noise, resulting in a percept which sounds like the intact word with a spurious bit of noise. It is hypothesized that the configurational properties of the word impair attention to the individual phonemes, and thereby induce perceptual restoration of the missing phoneme. If so, this impairment might be unlearned if the listeners can process individual phonemes within a word selectively. Subjects received training with the potentially restorable stimuli (972 trials with feedback); in addition, the presence or absence of an attentional cue, contained in a visual prime preceding each trial, was varied between groups of Subjects. Cueing the identity and location of the critical phoneme of each test word allowed subjects to attend to the critical phoneme, thereby inhibiting the illusion, but only when the prime also identified the test

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Attention within Auditory Word Perception:

Insights from the Phonemic Restoration Illusion

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Abstract

Phonemic restoration is a powerful auditory illusion that arises when a phoneme is removed from a word and replaced with noise, resulting in a percept which sounds like the intact word with a spurious bit of noise. It is hypothesized that the configurational properties of the word impair attention to the individual phonemes and thereby induce perceptual restoration of the missing phoneme. If so, this impairment might be unlearned if listeners can process individual phonemes within a word selectively. Subjects received training with the potentially restorable stimuli (972 trials with feedback); in addition, the presence or absence of an attentional cue, contained in a visual prime preceding each trial, was varied between groups of subjects. Cueing the identity and location of the critical phoneme of each test word allowed subjects to attend to the critical phoneme, thereby inhibiting the illusion, but only when the prime also identified the test word itself. When the prime only provided the identity or location of the critical phoneme, or only the identity of the word, subjects performed identically to those subjects for whom the prime contained no information at all about the test word. Furthermore, training did not produce any generalized learning about the types of stimuli used. A limited interactive model of auditory word perception is discussed, in which attention operates through the lexical level.

For many decades, psychologists studying visual perception have concerned themselves with attention. Researchers have studied attention when it is either divided among two or more stimuli, or focused in order to process information selectively. There are further distinctions that can be made in classifying the many variants of attention, particularly in delineating varieties of selective attention. Garner (1974, 1978), for example, has drawn a distinction between selective attention to specific stimuli within sets of stimuli and selective attention to attributes that generate the stimuli. Treisman (1969) constructed a taxonomy which differentiates among various types of selection; she, too, considered selection of the attributes of a stimulus a distinct type of attention.

These different types of selective attention have not generally been considered in theories of speech perception. Speech scientists have studied the role of attention, but they have primarily concentrated on attention to one of many inputs — the classic "cocktail party phenomenon" (Cherry, 1953) — while ignoring the role of attention within the perception of individual spoken words. Although the results from several speech perception paradigms — for example, phoneme monitoring and mispronunciation detection — could lend themselves to a discussion of within-word attention, results from these and similar paradigms have generally not been interpreted in terms of the role of attention in speech perception.

To facilitate the integration of attentional theories with models of speech perception, speech scientists have recourse to a large body of research on visual selection. Many of these experiments have examined selection of attributes of a stimulus by utilizing visual illusions, taking changes in the subjective magnitude of the illusion as indicative of the viewer's ability to process attributes selectively. Typically, the illusion chosen has been one in which the illusory

effects are believed to arise from the misdirection of attention to the global or configurational properties of the stimulus. In this case, the magnitude of the illusion may be lessened if viewers can selectively process the appropriate local properties of the stimulus.

Consider, for example, the Mueller-Lyer illusion (<——> vs >——<), in which the presence of the oblique lines induces an overestimation of the length of the horizontal line between the inwardly-pointing arrowheads. This illusion has sometimes been construed as a target (the horizontals) plus distractors (the obliques), the latter conferring the global illusory properties that misdirect attention from the target. If the viewer can somehow redirect attention to the target, ignoring the global properties of the stimulus, then there ought to be a resulting decrement in the magnitude of the illusion.

Historically, two techniques for directing subjects' attention have often been used to study visual illusions such as the Mueller-Lyer effect:

1. Training — subjects receive extensive practice with the appropriate stimuli, in the hope that they will learn to focus attention appropriately (e.g. Judd, 1902; Lewis, 1908);
2. Cueing — the target is made salient through contrasting hue or brightness, or spatial separation from the distractors, thus making it easier for subjects to attend to it (e.g. Coren & Girgus, 1972; Dewar, 1967).

The techniques used to study the Mueller-Lyer illusion as an attentional phenomenon may be applied to auditory illusions as well; there are a number of auditory illusions that may be due to attentional effects. One class of these illusions has recently been reviewed by Warren (1984). In these illusions, missing parts of an acoustic signal are perceptually restored, resulting in a complete percept of an incomplete stimulus. These effects have been observed for such

stimuli as broadband noise (Warren, Obusek, and Ackroff, 1972), pure tones (Bennett, Parasuraman, Howard, and O'Toole, 1984), and speech (Warren, 1970).

The present study focusses on the illusory restoration of missing speech sounds, an effect known as "phonemic restoration" (Warren, 1970). When the physical cues corresponding to one of the phonemes in a word are removed, and replaced with noise of the same duration as the now-missing phoneme, listeners usually report hearing the intact word (including the absent phoneme) along with some extraneous noise.

Samuel (1981a,1981b) introduced a methodology for studying the phonemic restoration illusion, based on its phenomenology. He constructed two versions of each word, one with a phoneme replaced by a bit of noise as described above and one with the bit of noise added on top of the phoneme. To the extent that the illusion occurs, the listener will be unable to discriminate the subjectively intact word (the version in which the noise actually replaces a phoneme) from the objectively intact word (the version in which noise was merely added on top of the phoneme.)

Subjects heard these words, one at a time, and made a forced choice about which version of the word, replaced or added, they thought they heard on that trial. This methodology provides false alarm rates (responding "replaced" to an ADDED item) and miss rates (responding "added" to a REPLACED item) for each subject, where a "hit" is defined as correctly identifying the replaced version of the word. These error rates were then used in a signal detection analysis. As a result, Samuel was able to separate perceptual discriminability, as measured by the signal detection parameter d', from postperceptual bias, measured by the signal detection parameter beta. Discriminability (i.e. d') is then taken to reflect the magnitude of the illusion: The more the subjectively restored phoneme and the actual phoneme sound different to the listener, the less the listener is inferred

to be experiencing the illusion. Because higher values of $\underline{d'}$ denote better discriminability, higher values of $\underline{d'}$ are taken to indicate a decrease in the magnitude of the illusion.

Using this methodology, Samuel (1981a, 1981b) has manipulated phonetic, lexical, and sentential contexts and differentiated between the effects each manipulation has at a perceptual _vs_. a postperceptual level of processing. For example, the acoustic similarity between the phoneme being replaced and the replacing noise determined the amount of restoration that occurred at a perceptual level; the better the acoustic match, the greater the magnitude of the illusion. At the lexical level, longer words produced more restoration than shorter words, and pronounceable nonwords (e.g. "pafis") yielded less restoration than real words (but see Samuel, 1985b); furthermore, the word length effect did not obtain when the critical phonemes were contained in the nonwords.

In examining lexical effects on the illusion, the limiting case is when there is no surrounding lexical context at all. If listeners still have difficulty in discriminating between replaced and added versions of the critical phoneme when the rest of the word is absent, the effect may be due to simple auditory masking. Samuel (1981a) examined subjects' ability to make the replaced-added discrimination, comparing performance with whole words to performance with only the critical portion of each word. Subjects very easily discriminated "speech-plus-noise" (segments excised from the added versions of the words) from "noise" (segments excised from the replaced versions of the words), but had great difficulty in discriminating between the two versions of the whole words. In fact, the only limit on subjects' performance with the segments was the bottom-up effect mentioned above: Subjects less easily discriminated between the two types of segments when there was a good acoustic match between the noise and the critical phoneme, such as between the white noise and fricatives. The results from

experiments comparing words _vs._ segments and real words _vs._ nonwords, as well as the effect of word length, indicate that the lexicon plays an active role in the phonemic restoration illusion.

The data currently available (Samuel, 1981a) suggest that sentential context acts differently. The extent to which the context predicted a missing phoneme had no effect on _d'_, and by inference, no effect on perception. On the other hand, predictibility affected subjects' postperceptual bias (_beta_): The more the sentence predicted the missing phoneme, the more confident subjects were that the phoneme was present.

The results of these experiments and others in the literature, imply a multi-level, interactive system for the perception of fluent speech. In such a system, phonemic restoration occurs as a consequence of both a top-down flow of expectancies from the lexical level to the lower levels in the system, and a bottom-up auditory match between the actual signal and the expected percept. There are limits to the interactivity of the system, however: Sentential constraints do not appear to affect the sub-lexical levels (see Samuel, in press, for more detail).

Missing from this description of the perceptual system is any speculation regarding the role of attention in the phonemic restoration illusion and, by extension, in speech perception. This model, like other current models of speech perception, considers the flow of information between the levels of the system, but does not address which of the processes might be subject to conscious control or which dimensions at one level might be inseparable to another level. However, at least one set of experiments has addressed this issue. Nusbaum, Walley, Carrell, and Ressler (1982) suggested that listeners have active control over the processes involved in auditory word perception and can attend to whatever level in the system

they find most useful. Their experiments examined phonemic restoration and employed Samuel's replaced-added methodology.

Part of Nusbaum et al.'s support for their claims about the role of attention came from an investigation of the effects of training on the phonemic restoration illusion. They presented subjects with 320 trials, all with feedback, using two sets of stimulus words. Each set consisted of the replaced and added versions of each of ten three-syllable words. Subjects received 240 trials of training with one set of words -- 12 passes through each version of each word in the set -- followed by a test for transfer of training with the second set of words. Subjects' discrimination performance improved during the first few passes through the stimuli, and this increased level of performance was maintained through the rest of training and on the transfer test. Nusbaum et al. inferred that subjects had learned to focus attention on processing the acoustic pattern of the words, and were thus able to shut off the top-down flow of expectancies invoked in explanations of the illusions. They concluded that listeners can focus attention on the sound of a word without necessarily processing its meaning.

Before accepting the generality of Nusbaum et al.'s conclusions, some points need to be made about the stimuli they used. First, there were few stimuli used overall, only ten three-syllable words per stimulus set. Second, the critical phoneme always occurred in the third syllable. With so few stimuli, all of which contained the target at the end of the word, subjects may simply have learned to ignore the first two syllables of the word. Nusbaum et al. claimed that subjects "adopted a more general strategy of attending to the phonetic pattern structure of words(p.99)." Another possibility is that subjects adopted a less general strategy of attending to the final syllable of words.

The present study, like that of Nusbaum et al., is intended to clarify how

attention can be deployed in speech perception. It differs from their study in three important ways. First, much larger training and transfer sets were used, and critical phonemes were chosen to include all positions, rather than just word-final. This design was employed to defeat any simple item-specific or position-specific stategies that subjects might want to adopt. Second, a significantly longer training period was used, to afford subjects the opportunity to adapt their attentional procedures. Finally, recall that historically the role of attention in visual illusions has been studied not only by giving subjects training but also by providing subjects with an attentional cue. If, in the phonemic restoration illusion, the global properties of the word misdirect listeners' attention away from the critical phoneme, then attending to the critical phoneme ought to result in a decrement in the magnitude of the illusion. If the effect of practice is to make the target more salient, then the training subjects receive in this experiment ought to make the replaced and added versions of each word more discriminable. At the same time, if an attentional cue enables listeners to attend to the critical phoneme, then subjects who receive such a cue ought to perform better in making the replaced-added discrimination than uncued subjects. Therefore, in addition to training, one group of subjects received information about the identity and location of the critical phoneme, in order to induce the subjects to attend to it.

Experiment 1

Experiment 1 examines the effect of training on the magnitude of the phonemic restoration illusion. In addition, this experiment assesses listeners' ability to focus attention on a given level of processing or a particular location within a spoken word by contrasting the performance of two groups of subjects who receive a

visual prime before each trial. For one group of subjects, the prime consists of the word they are about to hear on that trial, with the location and identity of the critical phoneme indicated by an asterisk. For a second group of subjects, the prime consists solely of the word, without revealing the critical phoneme. If the former group can use the extra information to focus attention appropriately, then their ability to make the replaced-added discrimination should be better than the latter group's. Furthermore, if practice can lead to better attentional allocation, and thereby enhance the salience of the critical phoneme, then subjects' ability to make the discrimination ought to improve over time.

Method

Stimuli

Stimulus construction. Each test word was spoken by the second author in an acoustically shielded room and recorded on audiotape. The word was then low-pass filtered at 4.8 kHz, digitized at 10 kHz (12-bit A/D), and stored on a PDP-11 disc file. For constructing the noise-replaced and -added version of the word, the critical phoneme (including any transitions) was first located within the word, both auditorily (through headphones) and visually (on a CRT), using a waveform editor. The replaced and added versions were then constructed using a slightly modified version of Samuel's (1981a) method:

Replaced items were created using Schroeder's (1968) speech-correlated noise technique to replace the critical portion of the digital waveform with white noise: Flipping the sign of half of the points, chosen at random, yields a sound that maintains the amplitude envelope of the original, but with a flat spectrum (i.e. white noise).

Added items were produced by adding together, point-for-point, the critical portions of the original and replaced versions. Because the amplitudes of the two components are the same, the listener hears speech at the original amplitude together with white noise with a matched amplitude.

Test words. Two sets of words were selected. Each set consisted of the replaced and added versions of 54 three- or four-syllable words, and represented the (3x3) factorial crossing of phone class and position of the critical phoneme, with six tokens per cell. In one-third of the words the critical phoneme was a fricative, in one-third a nasal, and in one-third a vowel; the critical phoneme was equally likely to occur at the beginning of either the first, second, or third syllable. In addition, the primary stress came on the first syllable for one-third of the words, on the second syllable for one-third, and on the third syllable for one-third.

Apparatus

All stimuli were stored on disc file in a PDP-11/23 computer. For presentation to the subjects, they were played out through a 12-bit D/A converter, amplified, low pass filtered (4.8 kHz), and played binaurally over high fidelity stereo headphones. Subjects heard the stimuli in an acoustically shielded room. The visual primes were presented on a computer terminal located in front of the subject. Subjects responded by pressing one of two labelled keys on the terminal's keyboard. All experimental events were controlled by the computer.

Procedure

Each trial began with the presentation of a visual prime, which remained on the screen for 750 msec, and contained either lexical and phonemic information or lexical information only. For one group of subjects (LEX&PHON) the prime consisted

of the word they were about to hear, with an asterisk or asterisks over the letter(s) indicating the position and identity of the critical phoneme. These subjects were told that the word they saw on the screen was the word they would hear on that trial, and that the letter under the asterisk was the one that would have noise added to or replacing it. For the other group of subjects (LEX) the prime consisted of the word they were about to hear. These subjects were told simply that this was the word they would hear on that trial.

After an interval of 250 msec following offset of the prime, subjects heard the test item. They were told to push the key marked "REPLACED" if they thought that noise replaced one of the phonemes in the word, and to push the key marked "ADDED" if they thought that noise was merely added on top of one of the phonemes in the word. (Subjects in the LEX&PHON condition were told to make this judgment with respect to the phoneme indicated by the asterisk.) The nature of the stimuli had been fully explained beforehand. Subjects were told to respond as accurately as possible, but to guess when necessary; a response was required on each trial.

As soon as the subject responded, feedback was provided: The screen displayed either the word "RIGHT" or the word "WRONG", contingent upon the subject's response. The computer then waited 2 sec, and initiated the next trial.

Words were presented in blocks. Each block consisted of two passes through each of the 54 words in one stimulus set, in random order. On the first pass, each word was randomly presented in either its added or replaced form. The form which was not presented on the first pass was presented on the second pass, so that each block contained both versions of each of the 54 words (108 trials). At the end of the block, subjects pressed "RETURN" on the keyboard when they were ready to begin another pass through the stimuli, newly randomized. Each session consisted of three blocks (324 trials), and lasted approximately 45 minutes.

Subjects participated in three sessions. Sessions 1 and 2 comprised the training trials. Session 3 tested for transfer of training, using the words from the stimulus set not used in the first two sessions. Session 1 was run on one day, followed by Sessions 2 and 3 on the next day (there was a two-minute break between Sessions 2 and 3.)

Subjects

Twenty-four subjects participated in Experiment 1, twelve in each of the two conditions. All were native English speakers with no known hearing problems. They received $8 or course credit for their participation.

Results

Two measures of restoration were calculated from the data. One measure, *d'*, quantifies the subjects' ability to discriminate between the two versions of each word. A *d'* score of zero signifies complete indiscriminability; in the context of this experiment, it would connote the subjects' inability to tell when the word was actually intact or merely sounded intact because they had restored the missing phoneme.

Insert Table 1 About Here

Table 1 gives the *d'* scores for both groups of subjects collapsed over blocks to yield session means. The first thing to notice is that receiving the attentional cue (the asterisk) enabled subjects to make the replaced-added discrimination better; the overall *d'* for subjects in the LEX&PHON group was 1.16,

while the overall $\underline{d'}$ for subjects in the LEX group was 0.73. A three-factor analysis of variance (Priming Group x Block [1-3] x Session [1-3]) verifies that the difference between the groups was significant ($\underline{F}$ (1, 22) = 6.72, $p < .02$.)

The result of the training manipulation contrasts with that of the attentional cue. The flatness of the learning curve for subjects in the LEX&PHON group is reflected in a null effect of Session, $\underline{F}$ (2,22) = 0.11, n.s. For subjects in the LEX group, there appears to have been some gain from the first to the second session of training; however, this trend failed to reach significance (Newman-Keuls test, $p > .05$.) Moreover, the LEX group's drop in performance in the third session relative to both of the earlier sessions was reliable (Newman-Keuls, both $p < .01$.) Thus, the training effects are not reliable for either group, and there is even evidence of negative transfer for the LEX group.

Insert Table 2 About Here

Recall that critical phonemes were selected from three different phone classes — fricatives, vowels, and nasals. Table 2 presents the $\underline{d'}$ scores broken down by phone class. The best bottom-up match yields the most restoration, replicating Samuel's (1981a, 1981b) results: $\underline{F}_{LEX}(2, 22) = 11.43$, $p < .001$; $\underline{F}_{LEX\&PHON}(2, 22)$ = 25.04, $p < .001$. The weak interaction between type of prime and phone class did reach significance, $\underline{F}$ (2, 44) = 3.52, $p < .05$.

The other measure of restoration calculated from the data was <u>beta</u>, which reflects subjects' response bias at a postperceptual decision stage. A <u>beta</u> greater than 1.0 reveals a bias toward responding that the word was intact, regardless of which version was actually presented; values less than 1.0 reflect the opposite bias. Another way to think about <u>beta</u> is as a confidence rating: A

high value (> 1.0) mirrors subjects' confidence that the word was intact; a low value (< 1.0), that the word was not intact. Either way, beta is taken as a measure of postperceptual processing.

Insert Table 3 About Here

Table 3 is analogous to Table 1, in that it presents the session means for the two groups, this time providing beta scores. A two way analysis of variance (Cue condition x Session) indicated that the bias for the LEX&PHON group (1.25) was reliably greater than the bias for the LEX group (1.10), $F\ (1, 22) = 4.98$, $p < .05$. As with the d' data, there was no effect of training on beta, $F\ (2, 44) = 0.63$, n.s. The significantly higher bias for the LEX&PHON group suggests that providing more information to subjects leads them to believe the stimulus was intact, regardless of whether it was.

Discussion

The data from Experiment 1 indicate that subjects who received a useful attentional cue experienced less of the illusion than subjects who received no such cue; the decrement in the magnitude of the illusion for subjects in the former group is indicated by their superior ability to discriminate the two versions of each word. Thus, the asterisk in the visual prime provided a salient cue that allowed subjects to focus attention appropriately.

Recall that Nusbaum et al. (1982) obtained a significant training effect, using phonemic restoration stimuli in which the critical phoneme was always in the third (final) syllable. At first glance, the data in Experiment 1 appear to be at

odds with those of Nusbaum et al., since we observed no improvement with practice. However, an interpretation of their results in terms of subjects learning to attend to the third syllable is consistent with the results of the current experiment. Nusbaum et al.'s subjects showed an overall gain of 0.37 <u>d'</u> units in going from the first to the subsequent blocks (each block included four passes through each version of their ten words). In our experiment, subjects could not use a strategy of listening for the third syllable only. On the other hand, half of the subjects knew, from the outset, where in the word to listen for the critical phoneme. Comparing performance of these subjects with that of subjects who did not know where to listen reveals an overall difference of 0.43 <u>d'</u> units, a difference comparable to the difference Nusbaum et al. observed for subjects following the first block. Thus, the interpretation of the earlier study and the effect of an attentional cue in the current experiment both lend support to the view of the phonemic restoration illusion as arising, at least in part, from a misdirection of attention, a misdirection that subjects can overcome — with the right help.

Note that not all "help" is beneficial to subjects: Practice alone did not benefit subjects. Curiously, for the group of subjects who did not receive an attentional cue (LEX), there was significant <u>unlearning</u> when new words were presented. The fact that for these subjects performance improved (nonsignificantly) between Session 1 and Session 2 suggests that the subjects did learn something, but whatever it was did not generalize — in fact, it hurt performance with new words. Apparently, whatever learning that occurred was item-specific. When presented with new words, the strategies subjects developed during the first two blocks were inappropriate, and led to poorer discrimination.

Unfortunately, confounded with this explanation for the negative transfer is the fact that the second and third sessions were presented contiguously. By the end of the third session, subjects had been doing the task for approximately an

hour-and-a-half. Perhaps a simpler explanation for the downturn in subjects' performance in the LEX group is just fatigue. Perhaps subjects in the LEX&PHON group would actually have improved if they, too, had not done two sessions consecutively. To test this possibility, it would be necessary to run the experiment over, spacing the sessions over three separate days.

Another question arises from the main effect of the attentional cue. Because there was no condition in which subjects received no information at all in the visual prime, we don't know how the two groups in the current experiment would compare to a group of subjects who receive no information prior to hearing each test word. Is it the case that the attentional cue allows subjects to make the discrimination better than when no cue is present, or is it the case that lexical information facilitates the illusion by priming the top-down flow of expectancies and that the attentional cue merely compensates in some way for the priming effect, perhaps by degrading the lexical effects of the prime? In other words, does an attentional cue buy subjects release from PR (phonemic restoration), or merely release from priming of PR? An appropriate control group is necessary to answer this question.

Experiment 2

Samuel (1985b) has indicated that, under some conditions, the presence of a visual prime facilitates phonemic restoration. Informing listeners of the identity of the test word appears to augment the usual top-down flow of information implicated in explanations of the illusion by pre-activating the lexical representation of the test item. If this occurred in Experiment 1, then it might affect any interpretation of the mechanism by which the attentional cue proved beneficial. That is, perhaps the attentional cue acted only to inhibit the usual

effects of a visual prime; for example, it may have caused subjects to fail to process sufficiently the lexical identity of the item by evoking more orthographically based processing of the prime. Such an inhibitory effect of the cue would result in performance of the LEX&PHON group which would be at best equivalent to receiving no information at all, and to the extent that the lexical information from the prime still interfered with subjects' processing, performance would be lower than if the prime contained no information. A comparison to a group of subjects for whom the visual prime contains neither lexical nor phonemic information would resolve this issue of whether the attentional cue improves perfomance in this task or merely compensates for diminished performance.

An alternative explanation for the observed difference between groups in Experiment 1 is that performance on the task is a function of how much information about the test item is provided. Providing listeners with the lexical identity might itself be beneficial, despite Samuel's claims to the contrary — after all, subjects in the LEX group in Experiment 1 did improve a bit before doing so poorly on the final block, a degeneration which may ultimately be attributable to fatigue. Providing listeners with the lexical identity of the item as well as the identity and position of the critical phoneme may simply have been even more beneficial.

To answer these questions, four groups of subjects were run in Experiment 2. Two groups were run in the conditions used in Experiment 1, LEX and LEX&PHON. One of the new groups provided an overall control for the other groups. This group, CONTROL, received a visual prime which contained no information about the test item, but instead served only as a warning that the test item was coming. The other new group, (PHON), received only information about the identity and position of the critical phoneme, without receiving any lexical information. Thus, the four groups represent a (2x2) crossing of phonemic and lexical information.

From the preceding analyses, two patterns of results might be observed. If lexical information facilitates restoration under the conditions used, then subjects in the LEX group should do worse in making the replaced-added discrimination than subjects in the CONTROL group. If, in addition, the beneficial effects of the attentional cue are in fact due to the successful focus of attention, then the subjects who receive only phoneme information (PHON) should be most adept at eluding the illusion; they ought to out-perform the LEX&PHON subjects because in the PHON condition subjects should have no debilitating effects of lexical information to contend with.

If, however, performance is simply a function of the amount of information provided by the visual prime about the upcoming test item, then the LEX and PHON groups both ought to make the discrimination better than the CONTROL group; the LEX&PHON group, for whom the prime contained two sources of information, ought to perform best of all.

A small control experiment was run to deal with a possible problem in the PHON condition. Several subjects in this condition reported that they tried to guess the upcoming word, based upon the cue. Although this strategy could sometimes work, it appears to have two detrimental side effects, even when the subject guesses correctly. First, some attentional resources are presumably required for this self-assigned additional task, reducing available capacity for the required judgment. Second, this strategy focusses attention on the lexical level, exactly the opposite of what this cue was intended to do.

Experiment 2b used two new attentional cue conditions designed to address this possibility. The cues were chosen to provide sublexical information, without inviting subjects to guess the upcoming word. One cue was the orthographic representation of the critical phoneme, without any positional information

(PHONONLY). In the other cue condition (POS), subjects saw a set of underlines (representing the letters of the word), with an asterisk indicating the location of the critical phoneme. These two conditions dissociate the phonemic and positional cues that were given together in the PHON condition of Experiment 2a. We may therefore ask whether subjects can use either of these cues to perform better than the CONTROL subjects of Experiment 2a, under conditions that discourage the use of a counterproductive strategy.

To decide if fatigue played a role in Experiment 1, Experiment 2a was run over three days instead of two, so that subjects were run for only 45 minutes at a time. This procedure eliminates the confounding of fatigue with transfer that existed in Experiment 1.

Method

Stimuli and Apparatus

The stimuli were the same two sets of words used in Experiment 1. As before, there were two versions of each word, one with noise replacing the critical phoneme and one with noise added on top of the critical phoneme. The apparatus was the same as in Experiment 1.

Procedure

The procedure for Experiment 2a was essentially the same as in Experiment 1, with the following modifications. Four groups of subjects were run. In addition to the conditions with lexical information alone (LEX) and with both lexical and phonemic information (LEX&PHON), two new conditions were run. For one group (CONTROL), the p[illegible] contained no information about the upcoming test word; for the

other group (PHON), the prime revealed the location and identity of the critical phoneme in the imminent test word, but not the identity of the word itself. In this way, the four types of visual primes in Experiment 2a represented a (2x2) factorial crossing of phonemic information (present or absent in the prime) with lexical information (present or absent).

For the PHON group, the visual prime consisted of the letter(s) corresponding to the critical phoneme embedded in a row of discrete underlines (_'s) that represented the other letters in the word. For example, if the test word were "vanilla", with noise replacing or added to the /v/, the subject would see

v _ _ _ _ _ _

on the screen prior to hearing the word. The subjects were informed about the nature of the primes and their relationship to the test words. For the CONTROL group, the visual prime consisted solely of a row of underlines corresponding to the letters of the word. These subjects were told that the cue served to indicate the imminence of a test word.

In the POS condition of Experiment 2b, each test word was preceded by a visual cue to the position of the critical phoneme. Thus, if the initial phoneme in "vanilla" was to be replaced or have noise added to it, the subject would see

*

_ _ _ _ _ _ _

In Experiment 2b's PHONONLY condition, the subject in this case would just see the letter "v" centered on the terminal screen.

Each session was run on a separate day. Each session again lasted approximately 45 minutes, so subjects in Experiment 2a were run for 45 minutes at a time on each of three consecutive days; subjects in Experiment 2b were run in a single 45 minute session.

Subjects

Ninety six subjects participated in Experiment 2, sixteen in each of the six conditions. All were native English speakers with no known hearing problems. They received money and/or course credit for their participation.

Results

Table 4 presents the mean d' scores of the four groups of subjects for the three sessions of Experiment 2a. Consider first the results for the two groups that were included in Experiment 1. Once again, the group receiving the attentional cue, LEX&PHON, showed a reduction in the magnitude of the illusion relative to the group without such a cue, LEX. Mean d' s for LEX&PHON and LEX were 1.10 and 0.88, respectively. This difference was marginally significant, $F\ (1,30) = 2.79$, $p = .10$.

Insert Table 4 About Here

As in Experiment 1, performance of subjects in the LEX group degenerated upon presentation of the new words. A Newman-Keuls test of the difference between the second and third sessions was significant, $p < .01$. The difference between the first and second sessions, which for this group had not reached significance in Experiment 1, was significant here (Newman-Keuls, $p < .05$). On the other hand, the first and third sessions did not reliably differ ($p > .05$). Also similar to Experiment 1 was the lack of any significant change over sessions of performance of subjects in the LEX&PHON group, $F\ (2, 30) = 0.37$, n.s.

Consider now the results of all four groups of subjects shown in Table 4. The overall means for the four groups were 0.81 (PHON), 0.88 (LEX), 0.88 (CONTROL), and 1.10 (LEX&PHON). The last group clearly stands apart from the other three; Newman-Keuls comparisons confirm this impression, with the LEX&PHON group reliably better than the others ($p < .01$) and no reliable difference among the other three (all $p > .05$).

Consistent with the earlier results, there was no discernible training effect for the two new groups. Neither group changed significantly over days, $F_{CONTROL}(2, 30) = 0.52$, n.s., and $F_{PHON}(2, 30) = 0.11$, n.s. The trend for the CONTROL group was toward better performance, while for the PHON group, performance showed some deterioration.

Recall that subjects were run in the POS and PHONONLY conditions of Experiment 2b because it appeared that some subjects in the PHON condition might be using counterproductive strategies. In fact, performance in the PHON condition did tend to be slightly worse than in the other conditions of Experiment 2a. The results of Experiment 2b, however, suggest that these differences were not important. The average $\underline{d'}$ score in the POS condition was 0.82, versus 0.76 in the PHONONLY condition. These values may be compared to the first session $\underline{d'}$ means for Experiment 2a's CONTROL (0.85) and PHON (0.83) conditions. The similarity of these numbers is supported by the results of a two way analysis of variance (Cue condition x Block [1-3]): There was no reliable effect of cue condition ($F(3,60) = 0.21$, n.n.); the effect of block ($F(2,120) = 1.86$, n.s.) and the cue condition x block interaction ($F(6,120) = 0.99$, n.s.) were also not significant. Thus, providing positional, phonemic, or positional and phonemic information did not help subjects to focus attention well enough to suppress the restoration illusion; nor did the guessing strategy used by some PHON subjects hurt performance.

Insert Table 5 About Here

Table 5 breaks the data down by groups and phone class. As in Experiment 1, there was a significant effect of the phone class of the critical phoneme: $F_{CONTROL}(2, 30) = 17.24$, $p < .001$; $F_{PHON}(2, 30) = 21.46$, $p < .001$; $F_{LEX}(2, 30) = 27.24$, $p < .001$; $F_{LEX\&PHON}(2, 30) = 29.99$, $p < .001$. There was little interaction of phone class with type of prime. This held for the pairwise comparison of the two original conditions, (even though the pattern between them was the same as in Experiment 1), and for the comparison of all four conditions, $F(2, 60) = 1.29$, n.s., for LEX and LEX&PHON, and $F(6, 120) = 1.65$, n.s., for all four conditions.

Insert Table 6 About Here

Table 6 presents the session means of the <u>beta</u> scores for the four groups. Looking at the main effect of the visual primes, the means for the four groups ordered themselves as follows: 1.10 (CONTROL), 1.25 (PHON), 1.31 (LEX), and 1.40 (LEX&PHON). An analysis of variance indicates that the points are distinct, $F(3, 60) = 3.06$, $p < .05$.

The bias results from Experiment 2b were consistent with the pattern in 2a. The mean <u>beta</u> scores in Experiment 2b were 1.07 for the POS condition, and 1.11 for the PHONONLY condition. These may be compared to Experiment 2's CONTROL (1.06) and PHON (1.30) results.

The data indicate that the bias to report stimuli as intact was highest for the cue condition with the most information, and lowest for the condition providing the least information. Overall, the bias was highest in the first block of a

session, and decreased as subjects used the feedback to bring their response probabilities into accord with the actual presentation probabilities of added and replaced stimuli.

Discussion

Experiment 2 contained a methodological replication of Experiment 1, and did replicate most of the results from the latter. For one thing, receiving an attentional cue again helped subjects to suppress the illusion. For another, performance of subjects in the LEX group degenerated upon presentation of the new words, even with the third session coming on a third day instead of immediately following the second session. Thus, fatigue can be ruled out as an explanation for the poorer performance observed during the third session. It can also be ruled out as an explanation for the lack of any reliable increase for the LEX&PHON group, since performance for this group did not improve over time in Experiment 2.

Another replication of Experiment 1 was the trend for the performance of subjects in the LEX group to improve from the first to the second session. In Experiment 1, this trend did not reach significance; in the present Experiment it did. Increasing statistical power by combining the results for the LEX condition from both Experiments indicates that each change, the increase in performance over the first two sessions and the decrease in performance upon presentation of a new stimulus set, was reliable. Therefore, the earlier conclusion, that learning for these subjects was item-specific, gained additional support from the results of Experiment 2. Since subjects in the LEX condition knew the identity of the upcoming word on each trial they could develop item-specific strategies, but these strategies lacked generality.

The type of learning (item-specific) which obtained for the LEX group was one question posed at the outset of Experiment 2. The other question involved the nature of the difference between the two groups from Experiment 1, a difference which replicated in Experiment 2. One hypothesis we considered was that performance in the LEX condition was depressed by lexical activation caused by the prime; the attentional cue in the LEX&PHON condition could serve to reduce this effect by directing attention to the phonemic, rather than lexical, level. Alternatively, we hypothesized that the difference between the two groups was simply a function of how much information was given to each group: The subjects in the LEX&PHON condition received more information, and discriminated better.

The PHON and CONTROL conditions were included in Experiment 2 to test these hypotheses. In brief, neither of the initial hypotheses was supported by the data. Lexical information did not facilitate perceptual restoration, as indicated by the lack of a difference between the LEX and CONTROL groups. Receiving the attentional cue, therefore, did enable subjects to focus attention in order to discriminate better between the replaced and added items, evidence for a reduction in the subjective magnitude of the illusion. The attentional cue, however, only enhanced the focus of attention when presented with lexical information. Receiving information about only the critical phoneme (the PHON condition) led to slightly poorer performance than receiving no information at all. Hence, no additivity of lexical and phonemic information sources was found, because each individual source provided nothing to summate.

In one respect, however, the predicted additivity of the sources did manifest itself. The different sources had an additive effect on <u>beta</u>, the measure of postperceptual processing. At some decision stage, then, more information does lead to a bias toward responding that the word was intact. Put another way, the more the subjects knew about the upcoming word, the more confident they were that

the word was all there; the more subjects knew about what was coming, the more they believed that it was there when it finally came.

General Discussion

The current experiments had a twofold purpose: to determine the extent to which attention plays a role in the phonemic restoration illusion, and to infer from this the nature of attention in auditory word perception. Inasmuch as the second purpose is an extrapolation from the first, the two will be considered one at a time.

Attention and Phonemic Restoration

The phonemic restoration illusion is generally construed in terms of the top-down flow of expectancies from the lexical level receiving sufficient confirmation from the actual signal to induce perception of an intact word (Samuel, 1981a). Because the illusion has been explained in this way, researchers have selected experimental manipulations that reflect this theoretical viewpoint. Changes in the magnitude of the illusion have occurred both as a function of the strength of lexical expectancy — varied, for example, by priming the test words or by including nonwords in the design (Samuel, 1981a, 1985b) — and as a function of the acoustic match between the critical phoneme and the replacing noise (Samuel, 1981a, 1981b). Little discussed in these results is where attention might play a role in this explanation of the illusion, and how it might account for some of these effects.

As we suggested earlier, in an attentional explanation of the illusion each

stimulus may be characterized as a target (the critical phoneme) plus distractors (the rest of the word). The working hypothesis was that the distractors configure and impair selective processing of the target; the distractors misdirect attention away from the target. When listeners do not specifically attend to the target, the lexical expectancy prevails and restoration occurs. In other words, in perceiving these stimuli, listeners process the word, not its attributes; they attend to the lexical level of processing, and to the extent that processing is not redirectd in some way, the absence of the critical phoneme is not processed sufficiently to disconfirm the lexical expectancy.

What happens, though, when something happens that causes attention to be redirected in processing the stimulus? When the critical phoneme and the replacing noise match acoustically, the signal provides confirmation of the lexical expectancy. Consequently, there is nothing about the stimulus which draws attention to the target. When there is a poor match, however, as between white noise and nasals in the current experiments, confirmation fails. In this case, attention has been drawn to the mismatch, and the listener is able to inhibit the top-down expectational flow. As a result, less restoration is observed. The mismatch yields an unexpected target, and this occurrence of an unexpected event is surprising, and therefore attention-compelling (Kamin, 1969).

Another way to redirect subjects' attention is through an explicit manipulation of attention, such as cueing. In the current experiments this inhibited restoration by allowing subjects to attend to the target. Subjects were unable to attend to the target when the prime contained only lexical information, because subjects still only had access to the lexical level: As subjects in this condition reported after the experiment, they used the prime to listen to hear if the word was all there, clearly not a successful strategy for the selective processing of attributes of the word. Subjects were equally — and perhaps

surprisingly — unable to attend to the target when the prime contained only phonemic information (location and/or identity). In this case, they lacked access to the lexicon, since both the size of the stimulus set and subject reports revealed that subjects were unable to identify the upcoming word until it came: Subjects in these conditions reported that they simply listened for that phoneme to occur in the upcoming word (when it came). The results of the priming manipulation indicate that selective processing of the phonemes in a word occurred, but only when the subject had access to the identity of the critical phoneme *via* the lexicon.

Why, then, did training fail, if focus of attention was possible? After all, training usually allows subjects to develop correct focus of attention. The answer is found in the nature of the manipulations that produced successful focus of attention, attentional cueing and acoustic mismatching.

For the cue to be successful in eliciting focus of attention, subjects needed to know the identity of each word. For training to be successful, subjects also needed to know the identity of each word: Only subjects in the LEX condition showed any training effects. This training can only be item-specific. If subjects need to know the identity of the upcoming word on each trial in order to *learn* to focus attention, then this learning cannot generalize to unfamiliar items. Because subjects in the LEX&PHON condition explicitly received information about where to attend within the word, they did not exhibit any learning: For these subjects, there was nothing more to learn.

With respect to the effect of acoustic mismatch on the illusion, the surprisingness of the replacing noise is attention compelling; with attention thus directed to the target, restoration does not occur. Training did not make the target more salient. If it had, subjects could have learned something about the

sounds of each word. In the experiment by Nusbaum et al. (1982), subjects learned to listen to the sounds at the end of the word, the sounds comprising the last 150 ms or so of the stimulus. Increasing the uncertainty of the items in the stimulus set by varying the position of the target and by increasing the number of items in the set effectively foiled such a strategy.

All of this converges on a theory of the role of attention in the phonemic restoration illusion. The illusion arises within the lexicon, as a consequence of the flow of expectancies from this level of processing, and within the signal, as a result of confirmatory matching by the replacing noise. Inhibition of the lexical expectancies can occur as a result of the selective processing of the critical phoneme, but this attentional shift depends on access to the lexical identity of the test word. The signal also provides a means for the focus of attention, through the surprisingness of the acoustic mismatch. Thus the illusion, arising from the lexicon and the signal, may be inhibited through the correct focus of attention, "correct" in that it must be mediated by either the lexicon or the signal. No result of the current experiments suggests that attention could be directed via the phonemic level of processing alone.

Attention and Auditory Word Perception

Samuel (in press) has proposed a limited interactive model of auditory word perception. In constructing this model, he cited the strong lexical effects on perception (Samuel, 1981a, 1985a) and the lack of perceptual consequences of sentential context observed in earlier phonemic restoration experiments (Samuel 1981a). In the model, the lexicon constrains the selection of lower level units and actively promotes the selection of lower level percepts. These lower levels,

of course, determine to some extent the lexical choice, but clearly the model emphasizes the centrality of the lexicon in speech percption.

It is not clear in this model, though, how attention mediates speech perception. Some theorists (e.g. Shiffrin and Schneider, 1977) have intimated that speech perception is a fully automatized process. Others (Nusbaum et al., 1982) have suggested that attention may be directed to any level of processing in the perception of speech. The current results, however, suggest a compromise: Attention may be directed to the phonemic level — it normally resides at the lexical level — but only via the signal or the lexicon.

Normally, the listener is aware of events at the lexical level; in listening to words, attention is focussed on the lexicon. Thus, lexical effects on lower levels of processing are typically automatic. However, listeners can to some extent control these effects through focus of attention. The current research does suggest that selective perception of phonemes is possible, but only when the listener has access to the relevant entry in the lexicon.

The lexicon, therefore, appears to occupy a position in speech perception of relative primacy. It provides the unit of currency for the interchange of the various levels of processing in speech perception (Samuel, in press), and it provides the level through which the listener has access to selective processing, as suggested by the current experiments.

Visual perception has long made use of a rich array of types of attention, one of which is attention to the attributes of a stimulus item. As Kahneman (1973) pointed out, "There is growing agreement that these varieties of selective attention are governed by different rules and are to be explained by different mechanisms(p.3)." It is up to speech perception researchers to delineate the "rules" and the "mechanisms" that characterize the different types of attention in

speech perception. The results of the present study indicate that attention is necessary to perceive phonemic units selectively, and is focussed through the level that has primacy in the perception of spoken words, the mental lexicon.

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Table 1

Cue Condition	Session Training 1	Training 2	Transfer 3
LEX&PHON	1.13	1.18	1.19
LEX	0.75	0.83	0.61

The effect of training and attentional cueing on the perceived magnitude of the phonemic restoration illusion in Experiment 1.
Results are broken down by training session and by information contained in the visual prime.

Table 2

Cue Condition	Phone Class		
	Fricative	Vowel	Nasal
LEX&PHON	0.75	1.31	1.80
LEX	0.49	0.85	1.04

The effect of phone class and attentional cueing
on the perceived magnitude of
the phonemic restoration illusion in Experiment 1.
Results are broken down by phone class
of the critical phoneme
and by information contained in the visual prime.

Table 3

Cue Condition	Session Training 1	Training 2	Transfer 3
LEX&PHON	1.23	1.24	1.27
LEX	1.07	1.17	1.07

Postperceptual bias as a function of training and attentional cueing in Experiment 1.
Results are broken down by training session
and by information contained in the visual prime.

Table 4

Cue Condition	Session Training 1	Training 2	Transfer 3
LEX&PHON	1.10	1.07	1.13
LEX	0.87	0.95	0.83
PHON	0.83	0.79	0.80
CONTROL	0.85	0.90	0.90

The effects of training and lexical and phonemic priming on the perceived magnitude of the phonemic restoration illusion in Experiment 2a.
Results are broken down by training session and by information contained in the visual prime.

Table 5

Cue Condition	Phone Class		
	Fricative	Vowel	Nasal
LEX&PHON	0.77	1.22	1.59
LEX	0.61	1.03	1.23
PHON	0.52	1.07	1.03
CONTROL	0.58	1.05	1.19

The effects of phone class and lexical and phonemic priming on the perceived magnitude of the phonemic restoration illusion in Experiment 2a.
Results are broken down by phone class of the critical phoneme and by information contained in the visual prime.

Table 6

Cue Condition	Session Training 1	 Training 2	 Transfer 3
LEX&PHON	1.31	1.47	1.41
LEX	1.21	1.31	1.40
PHON	1.30	1.19	1.26
CONTROL	1.06	1.12	1.12

Postperceptual bias as a function of training and lexical and phonemic priming in Experiment 2a. Results are broken down by training session and by information contained in the visual prime.

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